ION MICROPROBE ANALYSES OF SNC METEORITE MELT INCLUSIONS.

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Introduction

The SNC meteorites are generally considered to be pieces of Mars delivered to Earth via impact processes [1]. Some of these meteorites are igneous cumulates, and contain trapped melt within olivine and pyroxene crystals. Such trapped melt is common in terrestrial cumulates, and can yield information about volatiles and pre-eruptive magmatic conditions (e.g., [2,3]). We have analyzed melt inclusions from two cumulate SNC meteorites, Chassigny and LEW 88516, in order to better constrain two aspects of Martian geochemistry. First, some of the Chassigny inclusions contain small biotite crystals. The partitioning of Ba between biotite and silicate liquid is pressure dependent [4], and thus Ba analyses of both biotite and glass can yield information about the original depth of crystallization of the phases in the melt inclusions. Second, the Mo content of the Martian mantle can be used to infer conditions prevailing during core formation, since Mo is a moderately siderophile element. Mo (and other incompatible siderophile elements such as W and P) contents of basaltic rocks are commonly used to estimate the concentrations in the original mantle source, by comparison with a refractory incompatible lithophile element such as Ba or Ce (e.g., [5,6]). Since there are not many basaltic SNC meteorites, and Mo is rather difficult to analyze in bulk samples, we have analyzed the trapped melts to include in a reassessment of the Mo content of the mantle of Mars (there were previously only two analyses [7,8] constraining core formation models for Mo - [9,10]).

Analytical methods

Trace element analyses were performed by SIMS using the CAMECA IMS 3f instrument at Arizona State University. A series of andesitic glass standards were prepared for Mo and Ce, with concentrations ranging from 0.13 to 4.33 wt% MoO_3 and 0.08 to 2.95 wt% Ce_2O_3, as determined independently by electron microprobe analysis. Additional NBS glass standards were also utilized in the calibrations for $^{98}Mo^+$, $^{140}Ce^+$ as well as for $^{138}Ba^+$, $^{85}Rb^+$ and $^{89}Y^+$. The primary O^- ions were accelerated through a 15 kV potential, a primary ion current of 1 to 2 nA was focused on the sample over 10 to 20 µm spot diameter, and sputtered secondary ions were energy filtered with a sample offset of 75 V. Count times ranged from 10 to 300 seconds. Secondary ion intensities were normalized to $^{30}Si^+$ and concentrations of each element were calculated using standard calibrations and the $M^+/^{30}Si^+$. SiO_2 contents were determined by separate electron microprobe analyses. Glasses and biotite were analyzed for major elements and BaO by electron microprobe analysis using the CAMECA SX50 instrument at the University of Arizona.

Results

Many of the melt inclusions contain apatite crystals, which are potential carriers of Ce and Y. As a result, Ce and Y could be used to monitor apatite overlap. The analyses reported in Table 1 are those unaffected by apatite. Additional interferences for the $^{98}Mo^+$ analyses are $^{56}Fe^{42}Ca$ or $^{54}Fe^{44}Ca$ dimers, especially with overlap on a clinopyroxene; such analyses were discarded as well.

Table 1: All values are in ppm and represent the range measured in each section

	Rb	Ba	Mo	Ce	Y
Chassigny glass	8.7 - 48	400 - 830	0.26 - 1.10	7.1 - 8.8	0.34 - 1.6
Chassigny biotite	-	2800	-	-	-
LEW 88516	1.3 - 150	10 - 38	0.18 - 0.81	0.16 - 2.87	0.48 - 0.74

Equilibration conditions of Chassigny melt inclusions

The Ba and Ti contents of the biotite and adjacent glass from the Chassigny melt inclusion can be used to calculate a pressure and temperature of biotite-liquid equilibrium [4]. Given the SIMS and electron microprobe analyses, we calculate a pressure of 20 (± 6) kbar and 800 (± 50) ˚C. This pressure is higher than estimated previously [11], but consistent with several mineralogical characteristics of the coexisting melt inclusion silicates. First, the low measured H, Cl and F contents of the kaersutites [12,13] indicate the presence of a large oxy-kaersutite component in the melt inclusion amphiboles. Recent experimental studies indicate that such high oxygen contents could be favored at

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high pressure [14], even at the oxygen fugacities (FMQ) recorded in the SNC meteorites [8]. Second, although the high Al_2O_3 and TiO_2 contents of the pyroxenes in the melt inclusions were attributed to possible kinetic effects [11], they could also represent crystallization at pressures as high as 20 kbar, based on calculations done using Ca-QUIlF equilibria [15], pyroxene and olivine compositions [11], $aSiO_2 = 0.6$, and oxygen fugacities near the FMQ buffer. Such high pressures would indicate an original depth of nearly 200 km for Chassigny. This is close to the minimum melt depth inferred from experimental studies of Martian mantle analogs [17] (it may have been impact ejected [16] from a much shallower depth, after transport from a greater depth).

Mo content of the Martian mantle and metal-silicate equilibrium

Molybdenum is commonly normalized to Ce in order to calculate mantle depletion factors (e.g., [6]). Antarctic meteorites [18] and specifically pyroxenes in LEW 88516 [19] are known to have Ce anomalies; it is not surprising then that the LEW 88516 melt inclusion glasses have anomalously low Ce contents (less than chondritic). As a result, we have chosen to use Ba (instead of Ce) as a normalization element for the Mo calculations. The Mo/Ba ratios measured on the melt inclusions are just below those measured on terrestrial samples (Figure 1). Previous modeling of core formation in Mars have used Mo depletions based on only one or two Mo analyses (e.g., [7,8]). These new data, together with previous whole rock analyses, help constrain the Mo content of the Martian mantle to a factor of ~10 lower than chondritic — similar to previous estimates. Conclusions of earlier work [10] on conditions of metal-silicate equilibrium in the Martian mantle are reinforced by the new calculated depletions. The abundances of Mo and four other siderophile elements (Ni, Co, W and P) are consistent with those expected from early metal-silicate equilibrium in Mars, in the presence of a shallow peridotitic magma ocean (T = 1900-2000 K, P = 60-90 kb, fO_2 lower than the iron-wustite buffer, and S contents of 5-10 % in the core-forming metal [10]).

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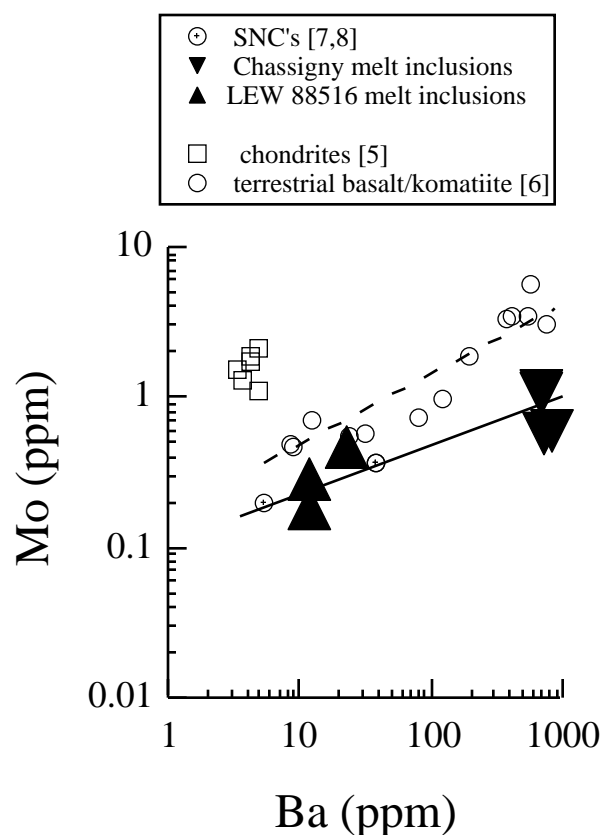

Figure 1: Mo vs. Ba for SNC and terrestrial samples. Dashed line is best fit through the terrestrial data and solid line is estimated fit through all SNC data